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PRIMARY CRUSHER SITE SELECTION IN OPEN PIT MINES - CASE STUDY IN SUNGUN COPPER MINE

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Abstract: Facility site selection, (such as Primary or in pit Crusher location) is one of the most important steps in mine de-sign process that has a significant impact on economy of the mining operation. This study covers an attempt to find the optimal location for primary crusher in order to support the expansion of Sungun copper mine, which is the second largest open pit mine in Iran. Recent exploration drilling has led to a considerable increase in the ore reserve. Therefore, Sungun started the studies followed with an expansion plan with the goal to increase the capacity from 14 to 28 Mt/Year within the next 8 years. In this paper, 14 effective parameters for finding the best location for a new crusher in five possible options were considered. The options were evaluated based on weighted linear combination method. The results show that the location in South East part of the open pit is the best option for locating of the new crusher. Finally, based on the economic parameters and copper price forecasts, pit optimization and sensitive analysis are applied. Results show that in the worst case, just 0.17 % of ore reserve is affected by the selected area and the minable reserve can cover 78 years of operation.

Keywords: Site Selection, Multi Criteria Decision Making, Sensitivity Analysis, Sungun Copper Mine

1 INTRODUCTION

Open pit mining is a huge operation in considerable amount of material which must be extracted and divided to ore and waste. Generally, ore is loaded to primary Crusher and waste is hauled to waste dumps (Shirazi et al., 2014). Site selection for all structures (etc. crusher, dumps, concentrator plants, office buildings, laboratories, and repair shops) define the destinations for material movement. For this reason, site selection present one of the most important decisions that has direct influence on economy in the mine, and it must be defined at an early stage, when many of the relevant information are unknown or (and) uncertain. It should be noted that some structures like crusher and dumps are more important than other structures, because relocating them take more time and cost, so poor decisions about their location (which seemed logical in one period of mine life

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cycle) could threaten the overall project. This stage should be conducted in concert with overall project planning. As a practical matter, much of the necessary data are collected at stages throughout the conceptual, pre-feasibility and feasibility phases, so site selection inevitably becomes an iterative process that must be updated as design study progresses (Hawley and Cunning, 2017).

Site selection of structures and facilities around an open pit needs to consider many parameters with different weights on decision-making process. Today, Multi-Criteria Decision Making (MCDM) methods are widely used for decision making process in order to choose the best possible solution out of the various number of criteria (Triantaphyllou, 2000). MCDM consists of many techniques like Weighted Linear Combination (WLC) (Hekmat et al. 2008), Analytical Hierarchy Process (AHP) (Stevanović et al. 2018), Preference Ranking Organization Method for Enrichment and Evaluations (PROMOTHEE) (Mohamadabadi, 2009), Elimination and Choice Expressing Reality (ELECTRE) (Govindan and Jepsen 2016), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Tsaur, 2011), Fuzzy Logic (FUZZY) (Gutiérrez et al. 2018), Multiple-Criteria Optimization and Compromise Solution (VIKOR) (Tavana et al. 2018; Janković et al. 2019). In many cases it is necessary that possible locations are cross-checked by other mining parameters in different phases hence, site selection inevitably becomes an iterative process that must be refined and updated with design study progresses (Hawley and Cunning, 2017).

The Sungun copper mine, a division of National Iranian Copper Industries – NICICo, is the second largest copper mine in Iran. It is placed in a mountain and steep region, so finding a flat area for making a structure is practically impossible. According to latest estimation for Sungun, conducted by CSA Global Consultant in 2015, Sungun resource tonnage is 1028 Mt (Measured + Indicated) and 2428 Mt (all classes) (Ltd, C.G.U., JORC, 2017). Based on the latest Sungun optimization performed by AMDAD Consultant in 2019, in order to make better financial results, Sungun should increase production from 14 to 28 Mt/Year in the next 8 years in two stages (LTD, A.M.D.A.D.P., 2019). When the problem considered in this study arose, the operating configuration of the mine included one crusher with the capacity of 2500 (ton/hour) and two concentrator plants (capacity of each of them is seven Mt/Year). Although the first crusher was located outside the pit in the initial design, it is inside the pit limit in the new pit optimization.

2 METHODOLOGY

Finding the best location of new crusher that can ensure fulfillment of planed capacity of development concentrator plants, was the main goal of this research. At the beginning, all important parameters which affect the general crusher site selection area were introduced and customized for Sungun copper mine. In the next stage, Weighted Linear Combination as one of the MCDM methods, was applied, with using expert opinion. In the following, a location with appropriate dimensions was considered in the selected area. An ultimate pit sensitive analysis based on copper price in depreciation life of concentrator plant was conducted in order to predict the influence of mine expansion on selected location. Figure 1 shows steps which are taken to find a location for development crusher in Sungun.

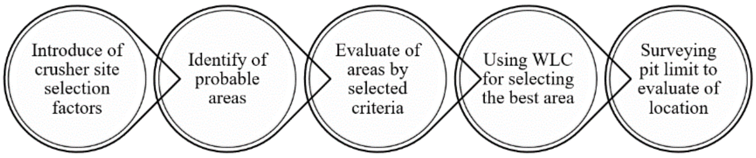

Figure 1 Steps to find optimal location for development crusher in Sungun

3 SITE SELECTION FACTORS

Site selection is one of the key activities for a new project or a capacity expansion project. The effective parameters that effect on the mine location facilities are divided into main divisions of underground and surface factors (Magda, 1985). Selecting the optimal location requires a wide range consideration of often competing objectives. Although, the choice of each location has its own requirements, but generally the key site selection factors can be divided into 6 criteria and 39 sub criteria that are shown in Table 1 (Hawley and Cunning, 2017):

Table 1 Key site selection factors (Hawley and Cunning, 2017)

Regulatory and Social	• permitting requirements • regulatory standards • land claims • inhabitant relocation • land and water use • visual quality • archaeology • artisanal mining	Terrain and Geology	• Topography • Geomorphology • natural hazards • bedrock geology • surficial geology • glaciology
Mining	• Proximity • Access • mining method • haul road grades • equipment options • capacity • alternative uses • mineral potential	Environmental	• Climate • Vegetation • Hydrology • Hydrogeology • water quality • dust • habitat
Geotechnical	• foundation slope • foundation shape • overburden type • overburden thickness • bedrock competency • groundwater conditions	Closure	• containment • reshaping • reclamation • water quality management

Social and environmental factors play a major role today in site selection activities, because of global awareness of environmental issues and the presence of regulatory agencies that closely monitor development activities in most countries (Ramcharan et al., 2005).

4 WEIGHTED LINEAR COMBINATION (WLC)

WLC is a simple and most often used Multi-criteria Decision Making Technique. The method is based on the weighted average. This method usually begins with defining a problem or criteria. Other stages are making decision matrix, normalizing of decision matrix, creating the weight of each attribute, and finally determining the best alternative. One of the benefits of this method is using qualitative and quantitative parameters together (Suleman and Baffoe, 2017). With n criteria and m alternatives decision matrix is given in Eq.1:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & x_{ij} & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

That X_{ij} is score of alternative *i* in relation to *jth* criteria. Decision matrix is then normalizes into matrix R (Eq. 2):

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & r_{ij} & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{2}$$

In this purpose, linear scale transformation is used to normalize attributes which is the division of a certain attribute by its maximum value. When both negative and positive attributes are available, it is possible to treat negative attributes as positive by taking the inverse of the outcomes; then the normalized outcome of r_{ij} is (Eq.3):

$$r_{ij} = \frac{x_{ij}}{\max_i\{x_{ij}\}} = \frac{\min_i\{x_{ij}\}}{x_{ij}} \tag{3}$$

Where X_{ij} is the valuation of the *ith* alternative with respect to the *jth* attribute. In this stage according to the importance of each criterion, the weight of each alternative is determined like (W_1, W_2 . . . W_n). Finally, the most preferred alternative A^* is selected such “Eq. 4”, Where W_j is the weight attribute (Hekmat et al. 2008).

$$A^* = \left\{ A_i \middle| \max_i \sum_{j=1}^{m} w_j r_{ij} \right\} \quad (4)$$

5 CASE STUDY – CRUSHER SITE SELECTION IN SUNGUN

As stated before for finding the best place for development crusher in Sungun, Weighted Linear Combination method was employed. After reserving space for pit and dumps, all area around the pit were divided to 5 parts (5 optional locations). These alternatives are (Area 1: West, Area 2: South & South West, Area 3: East & South East, Area 4: North East, Area 5: North West). All areas are vast, so after selecting the best ones it is necessary to restrict them based on the crusher's required space (100m × 110m). Figure 2 shows all alternative sites, reserved boundary for development concentrator plant, position of old crusher and concentrator plants, pit and dump areas.

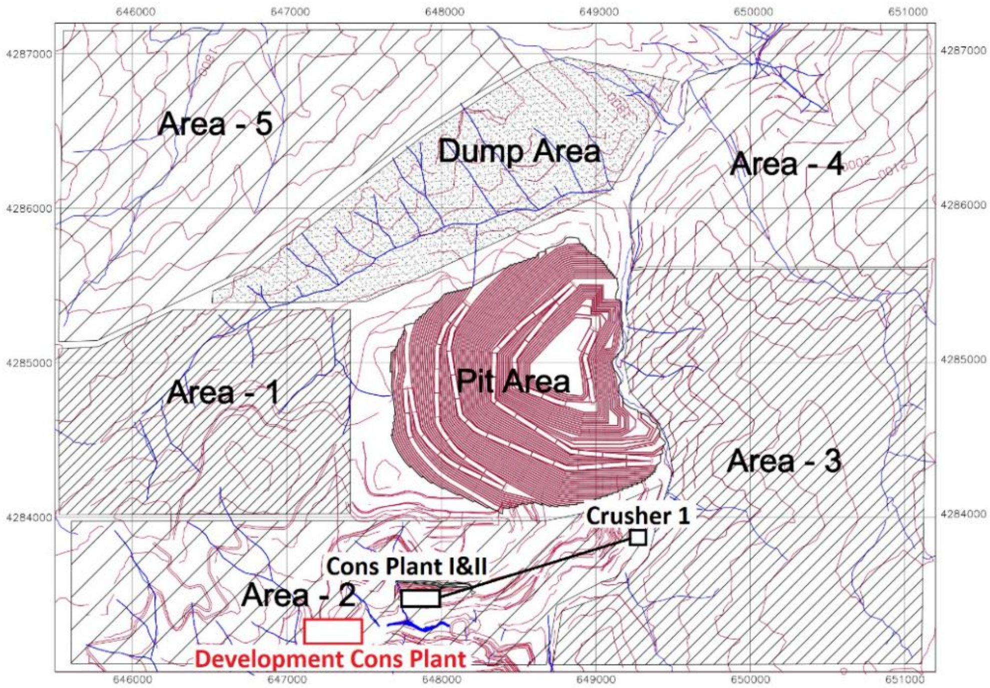

Figure 2 Topographic layout and definition of alternative sites (Area 1 – Area 5)

Rough topography, massive vegetation, cold climate, and difficult access puts Sungun in special situation. With the help of ten responsible experts from different fields (all from Sungun open pit), 14 criteria were evaluated they are shown in Table 2:

Table 2 Used criteria for crusher location selecting in Sungun

Criteria	**Area 1**	**Area 2**	**Area 3**	**Area 4**	**Area 5**
C1 land claim	Moderate	Moderate	Moderate	Moderate	Very High
C2 Geology	Weak	Weak	Strong	Strong	Moderate
C3 Flood risk	Very High	High	High	Moderate	High
C4 Environment	Good	Moderate	Moderate	Moderate	Bad
C5 Vegetation	Industrial	Industrial	Jungle	Jungle	Jungle
C6 Hydrology	Dry	Dry	in Valley	in Valley	Dry
C7 Slope	High	Moderate	Moderate	Moderate	Moderate
C8 Access	Difficult	Difficult	So Good	Good	Difficult
C9 Crusher to plant	Bad	Good	So Good	Moderate	Bad
C10 Mine to crusher	Bad	Bad	Good	Moderate	Moderate
C11 haulage cost	High	Moderate	Very Low	Low	High
C12 difference height	Moderate	Low	Low	High	High
C13 Space	Good	Moderate	Good	Good	Good
C14 Equipment	Bad	Good	Good	Moderate	Bad

The specification of each criterion in each alternative is compared to others, then they are rated from 1 to 5 (Table 3). The weighted coefficient of all criteria is considered equal. Score are normalized in each row, and they are shown in Table 4. For example, the normalized score for Criteria 1 for Area 1 is:

$$Normalized\ Scor\ (C1, Area\ 1) = \frac{3}{\max(3,3,3,3,1)} = \frac{3}{3} = 1$$

Based on that, weighted coefficient of alternatives is calculated. Cumulative results for each Area show the rating of analyzed options (Table 5). Results show that Area 3 has significantly better result than alternatives.

Table 3 Score matrix for site selection of crusher in Sungun Copper mine-All areas

Criteria	Area 1	Area 2	Area 3	Area 4	Area 5
C1 land claim	3	3	3	3	1
C2 Geology	2	2	4	4	3
C3 Flood risk	5	4	4	3	4
C4 Environment	5	4	4	4	1
C5 Vegetation	3	3	2	2	1
C6 Hydrology	5	5	3	3	5
C7 Slope	1	2	2	2	2
C8 Access	1	1	5	3	1
C9 Crusher to plant	1	4	5	3	1
C10 Mine to crusher	1	1	5	5	2
C11 haulage cost	1	3	5	4	1
C12 difference height	2	5	5	1	1
C13 Space	5	4	5	5	5
C14 Equipment	1	5	5	3	1

Table 4 Normalized score matrix for site selection of crusher in Sungun Copper mine-All areas

Criteria	Area 1	Area 2	Area 3	Area 4	Area 5
C1 land claim	1	1	1	1	0.33
C2 Geology	0.5	0.5	1	1	0.75
C3 Flood risk	1	0.8	0.8	0.6	0.8
C4 Environment	1	0.8	0.8	0.8	0.2
C5 Vegetation	1	1	0.67	0.67	0.33
C6 Hydrology	1	1	0.6	0.6	1
C7 Slope	0.5	1	1	1	1
C8 Access	0.2	0.2	1	0.6	0.2
C9 Crusher to plant	0.2	0.8	1	0.6	0.2
C10 Mine to crusher	0.2	0.2	1	1	0.4
C11 haulage cost	0.2	0.6	1	0.8	0.2
C12 difference height	0.4	1	1	0.2	0.2
C13 Space	1	0.8	1	1	1
C14 Equipment	0.2	1	1	0.6	0.2

Table 5 Weighted coefficient of alternatives for Criteria in Sungun crusher site selection

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	Result
Area 1	0.07	0.04	0.07	0.07	0.07	0.07	0.04	0.01	0.01	0.01	0.01	0.03	0.07	0.01	0.60
Area 2	0.07	0.04	0.06	0.06	0.07	0.07	0.07	0.01	0.06	0.01	0.04	0.07	0.06	0.07	0.76
Area 3	0.07	0.07	0.06	0.06	0.05	0.04	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	***0.92***
Area 4	0.07	0.07	0.04	0.06	0.05	0.04	0.07	0.04	0.04	0.07	0.06	0.01	0.07	0.04	0.75
Area 5	0.02	0.05	0.06	0.01	0.02	0.07	0.07	0.01	0.01	0.03	0.01	0.01	0.07	0.01	0.49

All further studies focused on Area 3 as the most suitable limitation for the crusher construction. After field visits, an area with lower forest, less steep slope and better access to mine was selected for making final design. According to specification and constructive characteristics a flat area equal to one hectare with convenient access to mine is needed. In order to provide these conditions in Sungun, it is necessary to cut 870,000 cubic meters of mountain. Figure 3 Shows a view of selected location in Area 3 for the development crusher, relative to new concentrator plant.

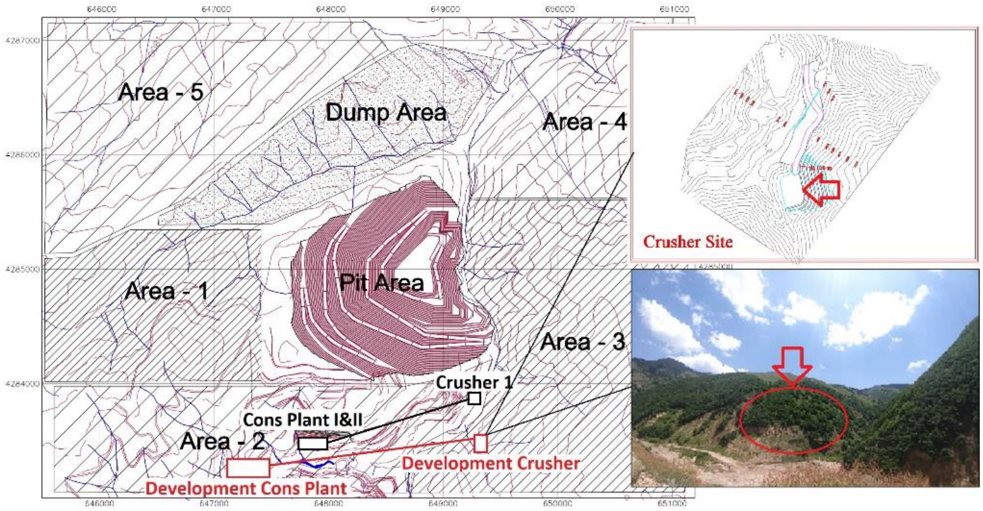

Figure 3 Location of development crusher in Area 3

6 SENSITIVITY ANALYSIS

Development crusher in Sungun is designed as fixed type, and its position must remain the same until the end of the depreciation life of the concentration plant (20 years). Therefore, in this project the estimated price of copper in 2040 is the basis for a sensitivity analysis. Obtained statistic for monthly data (2005 to 2019) shows prediction for the price of copper which is estimated to be 7450 $/ton in 2040 and copper price will be 4150 – 13200 $/ton with confidence factor of 95 %. For the analysis of the crusher position, a price of 13.000 $/ton was considered because it provides the highest expected open pit limits. Other parameters used for optimization are given in Table 6.

Table 6 Main Sungun optimization parameter

Mining Cost (Waste)	Mining CAF	Concentration Cost	Mining Recovery	Concentration Recovery	Dilution	Discount Rate
1.5 $/ton	1.5	6.2 $/ton	95%	87.50%	5%	10%

Optimization is done by NPV Scheduler software (Version 4.28.22.0). To investigate influence of price on pit limits, multiple pit contours were generated (each one is for a different price). In addition, reduction of pit reserve by selected crusher location is also determined. The result is shown in Table 7 and Figure 4.

Table 7 Reserve (all classes + different prices) Influence of crusher limit on reserve

Scenarios	CU price ($/ton)	Minable Reserve (Mt)	Remained Resource (Mt)	Reduction in minable Reserve (%)
MII-3500*	3500	921	60	0
MII-4800	4800	1820	21	0
MII-6500	6500	1963	15	0
MII-13000	13000	2180	5	0.17

*MII-3500: Ultimate pit obtained in copper price of 3500 $/ton with all classes

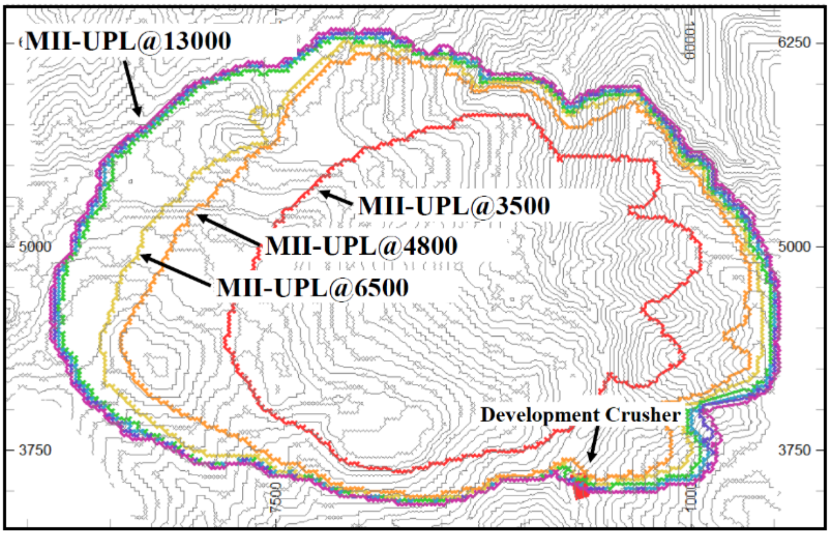

Figure 4 Situation of development crusher instead of ultimate pit boundary

According to given results, ultimate pit limits for the current price of copper (6500 $/ton) does not touch development crusher's limit, but with prediction copper price for next 20 years (13,000 $/ton), the ultimate pit will touch it. The mine life for this situation is 78 years old, which is much more than depreciation life of concentrator plant and in this scenario, only 0.17 % of reserves will be affected.

7 CONCLUSION

Site selection in mines is a critical activity which has a major impact on the mining economy. Mines use different strategy for site selection but one of the best ways for that is using different multi criteria decision making methods like WLC, AHP, PROMOTHEE, ELECTRE, TOPSIS and VIKOR. One of the simplest and most practical of decision-making methods is Weighted Linear Combination (WLC) that is used in this study. For selection of the best Area for Sungun development crusher, 14 criteria for five alternatives were checked. Results show that Area 3 (on the South East of Sungun current pit) is the best solution. Using MCDM methods have many advantages, but it is important to emphasize that the success of the method largely depends on the expert evaluation of the criteria. In this case study, after selecting the best solution for crusher location, the selected Area was further validated by a sensitivity analysis for prediction of copper prices in next 20 years (depreciation life of the concentration plant). Results show selected location is in a safe limitation and ultimate pit of mine does not touch it for 78 years. Using this method for site selection in mining projects is relatively quick, easy and it is recommended, if sufficient information for all relevant parameters and their weight will be available.

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